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Applicant(s):	Matsushita Electric Industrial Co., Ltd.

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Commissioner, Patent Office Hisamitsu Arai

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Japanese Patent Application No. 8-236317

[Name of Article]	Abstract	1
[Blanket Power of Attorney No.]		9308195
[Group Needed?]	Yes	

[Name of Document] Specification

[Title of Invention] Photomask and pattern formation method

[Claims]

[Claim 1] A photomask used at the time when a photomask with a phase difference of 180° in translucent regions with an opaque region interposed therebetween is used to expose a resist to form a resist pattern on said opaque region, characterized in that it has a plurality of widths depending on the interval between patterns adjacent to said opaque region.

[Claim 2] The photomask according to Claim 1 wherein the width of the opaque region is caused to be different between regions where there is formed a pattern wherein the interval between adjacent patterns is 0.7 λ/NA or greater and regions where there is formed a pattern wherein the interval between adjacent patterns is 0.5 λ/NA or less.

[Claim 3] A photomask used at the time when a photomask with a phase difference of 180° in translucent regions with an opaque region interposed therebetween is used to expose a resist to form a resist pattern on said opaque region, characterized in that the width x of the translucent region of said photomask where there is formed a pattern wherein the interval between adjacent patterns is at least 6 or more times the resist line width satisfies the inequality $0.5\ \lambda/NA \leq x \times$ (reduction ratio of the projection optical system) $\leq 0.8\ \lambda/NA$.

[Claim 4] A pattern forming method wherein a photomask with a phase difference of 180° in translucent regions with an opaque region interposed therebetween is used to expose a resist to form a resist pattern on said opaque region, characterized in that a photomask which has a plurality of widths depending on the interval between patterns adjacent to said opaque region is used.

[Claim 5] The pattern forming method according to Claim 4 wherein the width of the opaque region is caused to be different between regions where there is formed a pattern wherein the interval between adjacent patterns is 0.7 λ/NA or greater and regions where there is formed a pattern wherein the interval between adjacent patterns is 0.5 λ/NA or less.

[Claim 6] A pattern forming method wherein a photomask with a phase difference of 180° in translucent regions with an opaque region interposed therebetween is used to expose a resist to form a resist pattern on said opaque region, characterized in that the interval between all adjacent patterns is a separation of at least 0.65 λ/NA or greater.

[Claim 7] A pattern forming method wherein a photomask with a phase difference of 180° in translucent regions with an opaque region interposed therebetween is used to expose a resist to form a resist pattern on said opaque region, characterized in that the width x of the translucent region of said photomask where there is formed a pattern wherein the interval between adjacent patterns is at least 6 or more times the resist line width satisfies the inequality $0.5\ \lambda/NA \leq x \times$ (reduction ratio of the projection optical system) $\leq 0.8\ \lambda/NA$.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to the formation of fine patterns in the lithography process in the manufacture of semiconductor integrated circuits.

[0002]

[Prior Art]

Design rules for semiconductors have become steadily finer in recent years and now semiconductor chips on the 0.2 μm level have begun to appear on the market. With such a flow toward finer rules, the exposure wavelengths in lithography have also shifted from the g-line to the i-line and to KrF excimer lasers. However, stepper development for the next-generation ArF excimer laser is lagging due to the effects of absorption by lens materials and the like, so studies of various ultra-resolution technologies for KrF excimer lasers have been performed. The Levenson-type phase-shift mask is the technology that has the best resolution among these.

[0003]

Here follows an example of pattern formation with a conventional Levenson-type phase-shift mask.

[0004]

Fig. 8 is a step cross section for the conventional pattern formation method. In Fig. 8, 21 is a positive resist, 22 is a substrate, 23A and B are exposure light, while 24 is a mask. 23A illuminates the mask 24, while 23B is imaged upon the resist 21. 25 is an opaque region, while 26A and 26B are translucent regions and 26B is set such that the phase of the exposure light 23 is 180° different from that at 26A. Here follows a description of a pattern formation method constituted as such.

[0005]

In Fig. 8(a), first the substrate 22 is coated with positive resist 21. The positive resist 21 is a chemical amplification type resist for KrF use, coated to a film thickness of 0.5 micron. Next, the positive resist 21 is exposed through the phase-shift mask 24.

[0006]

The exposure conditions of the stepper used in the experiment were: exposure wavelength λ=248 nm, NA=0.48, σ=0.30, and the Levenson phase-shift mask used had quartz carved as shown in Fig. 6(b) to invert the phase by 180°.

[0007]

First, the exposure light 23A illuminates the phase-shift mask 24 and the light is diffracted depending on the pattern density. In the case of a Levenson phase-shift mask, the phase with the opaque region interposed is 180° different, so 0-order light and even-term order light is canceled in the left and right translucent areas and does not appear, but the ±1, 3, 5 and other order light is refracted at half the angle of a normal mask. Light refracted at an angle below a specific angle is transmitted through a projection lens to image a pattern upon the resist in the manner of light 23B, so with a Levenson phase-shift mask approximately twice the resolution is obtained as compared to an ordinary mask.

[0008]

After the aforementioned pattern exposure of Fig. 6(b), a PEB (post-exposure bake) is performed and development is performed in an ordinary aqueous alkaline solution to form the resist pattern (Fig. 6(c)). In this experiment, a 0.16-μm line and space pattern much finer than the exposure wavelength was resolved.

[0009]

[Problems that the Invention is Intended to Solve]

However, we found that with a configuration such as the aforementioned, if the pattern interval is different at the same line width, there is a problem in that the resist dimensions transferred upon the wafer vary due to the light proximity effect.

[0010]

The 21 X in the conventional Fig. 6(c) is a 0.16-μm L/S pattern and the 21 Y is a 0.16-μm line/0.48-μm space, but the respective resist dimensions are formed with 21 X formed at 0.16 μm and 21 Y becoming 0.20 μm and thus the difference between the two dimensions became 0.05 μm. This is thought to be because of the pattern pitch changing due to the light proximity effect. In the case of forming an ordinary transistor gate, the target for dimensional fluctuations is ±10% of the line width, so at a line width of 0.16 μm, this must be kept to just over 0.03 μm. Thus, the conventional pattern formation method cannot be used for the pattern formation of a transistor gate that requires dimensional accuracy.

[0011]

Therefore, the present invention came about in light of the aforementioned problems and its object is to provide a fine pattern formation method with low line-width dispersion using a phase-shift mask.

[0012]

[Means of Solving the Problems]

In order to solve the aforementioned problems, the photomask of the present invention comprises a photomask used at the time when a photomask with a phase difference of 180° in translucent regions with an opaque region interposed therebetween is used to expose a resist to form a resist pattern on said opaque region, characterized in that it has a plurality of widths depending on the interval between patterns adjacent to said opaque region and in that the width x of the translucent region of said photomask where there is formed a pattern wherein the interval between adjacent patterns is at least 6 or more times the resist line width satisfies the inequality $0.5\ \lambda/NA \leq x \times$ (reduction ratio of the projection optical system) $\leq 0.8\ \lambda/NA$.

[0013]

Moreover, by using the aforementioned photomask, the pattern formation method of the present invention changes the light intensity and light profile transmitted through the mask or eliminates certain patterns, and so even in line patterns of different intervals, the distribution of widths becomes narrower at the threshold value for the light intensity distribution, so it is possible to form a resist pattern with a nearly uniform line width.

[0014]

[Embodiment of the Invention]

Here follows a description of a pattern formation method as one embodiment of the present invention made with reference to figures.

[0015]

(Embodiment 1)

Fig. 1 is a step cross section for the pattern formation method in Embodiment 1 of the present invention. Fig. 2 is a diagram of the mask structure when a portion of the phase-shift mask of the embodiment shown in Fig. 1 is seen from the wafer side. In addition, Fig. 3 shows the light intensity distribution at the time of imaging on the resist.

[0016]

In Figs. 1 and 2, 1 is a positive resist, 2 is a substrate, 3A and 3B are exposure light, where 3A illuminates the mask while 3B is light that is transmitted through the mask and imaged on the resist. 4 is a photomask, 5, 5A and 5B are opaque regions, 6A and 6B are translucent regions and 6B is set such that the phase of the exposure light is inverted 180° from that at 6A. Here follows a description of the operation of a pattern formation method constituted as such, making use of Fig. 1, Fig. 2 and Fig. 3.

[0017]

In Fig. 1(a), first the substrate 2 is coated with positive resist 1. The resist is a chemical amplification type resist for KrF use and the film thickness is set to 0.5 μm. Next in Fig. 1(b), the exposure light 3A illuminates the phase-shift mask 4 and the exposure light 3B transmitted through the mask exposes the positive resist 1. Note that the exposure conditions of the stepper used in the experiment were: exposure wavelength λ=248 nm, NA=0.48, σ=0.40, and a 5:1 reduction type projection exposure apparatus was used. The phase-shift mask 4 used was a carved type whereby the phase is changed by 180° by carving the quartz substrate.

[0018]

Here follows a description of the details of the aforementioned phase-shift mask of Fig. 1(b) made using Fig. 2. 5A and 5B of Fig. 2 are locations where fine resist patterns are formed upon the wafer, and xa and xb indicate their respective widths. 5A is a region wherein a 0.16-μm L/S pattern is formed upon the wafer, while 5B is a pattern region of 0.16-μm lines/0.48-μm space intervals,

both of which are present upon the same mask. Exposure is performed with a 5:1 reduction stepper, so the mask pattern is transferred to the wafer at a 5:1 reduction. Thus, the mask dimensions of Fig. 1(b) become 5 times the actually transferred resist dimensions. The width xa of the opaque region 5A used in this embodiment is 0.80 µm, while the width of the opaque region in the y area is 0.50 µm.

[0019]

Fig. 3(a) shows the spatial light intensity upon the wafer after being transmitted through the mask of Fig. 2, while Fig. 3(b) shows the spatial light intensity when the mask compensation is not performed but rather the original pattern dimensions of 0.80 µm are used.

[0020]

In Fig. 3, the broken line indicates the light density at which a 16-µm L/S is formed at 1:1. The resist is a positive resist, so resist is formed in the portions below the broken line. Therefore, the resist line width thus formed is equivalent to the width of the light intensity distribution cut by the broken line. In a, the 0.16-µm lines/0.48-µm spaces are formed to 0.171 µm, but in b this becomes 0.190 µm. By adjusting the width of the opaque region of the phase-shift mask in this manner, it is possible to change the light intensity upon the wafer and adjust the dimensions.

[0021]

Thereafter, the resist exposed at such a light intensity was subjected to PEB (post-exposure baking) and then developed for 60 seconds in an aqueous alkaline solution to form the resist pattern 1x shown in Fig. 1(c). A resist pattern with a 0.16-µm line width was formed precisely with a dimensional accuracy of ±10% or less.

[0022]

By means of this embodiment as described above, by changing the width of the opaque region of the phase-shift mask, it is possible to form lines with the same line width but different pattern intervals accurately according to the design dimensions.

[0023]

(Embodiment 2)

Here follows a description of the pattern formation method in embodiment 2 of the present invention made with reference to diagrams. Fig. 4 is a representation of the relationship between the

0.16-μm line width and the pattern interval when a phase-shift mask with a 180° different phase in the translucent regions with a long, narrow opaque region interposed therebetween is used, found by means of a light intensity simulation. The simulation conditions were: exposure wavelength λ=248 nm, NA=0.60, σ=0.3, and the threshold light density was set at that at which a 16-μm L/S pattern becomes 1:1.

[0024]

In Fig. 4, the black circles indicate those wherein mask compensation was not performed, and the width of the opaque region on the mask for all patterns was, when converted to a value upon the wafer (opaque region width × reduction ratio), the same 0.16 μm as in the resist pattern. On the other hand, the white triangles show that in a pattern wherein the design interval between adjacent patterns becomes 0.67 λ/NA or greater, the opaque region width upon the mask was set to 0.10 μm when converted to a value upon the wafer. By compensating for the width of the mask opaque regions, one can see that the MAX-MIN width of the line width was greatly reduced to roughly half.

[0025]

Here follows a description of the reasons why mask compensation is performed in patterns wherein the interval between adjacent patterns is 0.67 λ/NA or greater.

[0026]

To wit, when mask compensation is performed in patterns wherein the interval between adjacent patterns is 0.67 λ/NA or less, as is clear from the trend in the white triangles of Fig. 4, the actual pattern line width conversely becomes smaller than 0.16 μm. Doing so, it is thought that the case of not performing mask compensation would rather become closer to 0.1 μm. Therefore, performing mask compensation with respect to patterns wherein the interval between adjacent patterns is 0.67 λ/NA or greater is thought to be preferable.

[0027]

In this manner, in this embodiment, the opaque regions of masks for patterns wherein the design pattern interval is 0.67 λ/NA or greater were made 0.10 μm when converted to upon the wafer, while patterns with smaller intervals were made 0.16 μm, thereby laying out two opaque bandwidths upon the mask. The predicted dispersion in line width for this can be reduced to roughly half its value.

[0028]

Note that in this embodiment, the width of the opaque regions in mask patterns is varied taking a pattern interval of 0.67 λ/NA as the boundary, but meritorious effects can still be obtained by making the width of the opaque region of a mask pattern different in at least regions wherein the pattern interval is 0.5 λ/NA or less and regions wherein the pattern interval is 0.7 λ/NA or greater.

[0029]

(Embodiment 3)

Here follows a description of the pattern formation method in embodiment 3 of the present invention made with reference to diagrams. Fig. 5 is a representation of the relationship between the line width and the pattern interval when a phase-shift mask with a 180° different phase in the translucent regions with a long, narrow opaque region interposed therebetween is used, found by means of a light intensity simulation. The pattern interval is normalized in λ/NA by converting the translucent region width upon the mask to a value upon the wafer.

[0030]

As is evident from Fig. 5, at all line widths, when the pattern interval is between the normalized values of 0.5 and 1, the line width rapidly becomes wider with the resist line width becoming greatest at a normalized value of 1, and then showing a trend of dropping gradually thereafter.

[0031]

For example, if we consider the example shown by the white triangles in Fig. 5, the normalized line width takes a minimum in the vicinity of a pattern interval of 0.4 λ/NA, and then the normalized line width takes a maximum in the vicinity of a pattern interval of 1.0 λ/NA, and thereafter it decreases gradually as the pattern interval increases. Therefore, in order to suppress line width dispersion to a certain degree, one can see that it is sufficient to avoid using the region wherein the interval with adjacent patterns becomes narrower than a normalized value of 0.65.

[0032]

In an actual experiment, design rules were determined such that there are no pattern intervals with a normalized value of 0.7 or less, and a 5:1 reduction type projection exposure apparatus with

a exposure wavelength of λ=248 nm, NA=0.48 and σ=0.40 was used to expose a 0.16-µm line width resist pattern. The dimensional dispersion obtained by experiment was kept to 0.16 µm±10%.

[0033]

By limiting the interval with adjacent patterns present upon the wafer to 0.65 λ/NA or greater as in the above, it is possible to suppress dimensional dispersion.

[0034]

(Embodiment 4)

Here follows a description of the pattern formation method in embodiment 4 of the present invention made with reference to diagrams.

[0035]

Fig. 6(a) is a mask structural diagram of a portion of the mask illustrating this embodiment when seen from the wafer side. Fig. 6(b) is a mask structural diagram of a portion of a conventional phase-shift mask when seen from the wafer side. In Fig. 6, 15 is the opaque region, while 16A and 16B are translucent regions with a mutual phase difference of 180° from each other. In addition, Fig. 7 shows the trend in the light intensity distribution in the case wherein the width of the translucent region of the phase-shift mask of the present invention is varied.

[0036]

Here follows an explanation of its meritorious effects using Fig. 6 and Fig. 7.

In Figs. 6(a) and (b), the fine line patterns upon the wafer are separated from the adjacent pattern by a pattern interval 6 or more times the line width. In this embodiment, in the aforementioned region wherein the patterns are separated from the adjacent pattern by a pattern interval 6 or more times the line width, as shown in Fig. 6(a), a specific limit width x is set in the translucent regions 16A and 16B regarding such patterns. To wit, they are formed for regions wherein the phase is 180° different so that the translucent region does not become wider. Note that when a translucent region as shown in the aforementioned Fig. 6(a) is formed, light will not be irradiated upon portions through which light should be transmitted, but it is sufficient to irradiate them with light by means of a subsequent re-irradiation.

[0037]

In this regard, since there is no such specific width in Fig. 6(b), the whole area up to the adjacent pattern becomes the translucent regions 16A and 16B. For this reason, the line width is easily changed because the translucent region is different depending on the pattern interval in patterns that have such wide intervals.

[0038]

However, if a specific translucent region width x is decided upon as in this embodiment shown in Fig. 6(a), even if the pattern interval is different, the light intensity transmitted through the translucent region does not change, so it is possible to form a resist pattern with good dimensional accuracy. In addition, in Fig. 6(b), at the time of laying out the pattern, since one translucent region is shared by two patterns, it is necessary to pay attention to the phase at all times. However, in the case of a wherein one pattern has a pair of translucent regions to the left and right, this has an advantage in that there is no need to pay attention to the phases of the surrounding translucent regions.

[0039]

Fig. 7 shows the results of using a simulation to investigate the trend in the light intensity distribution in the case of varying the translucent region width x of a phase shift mask in a 16-μm isolated pattern. The y-axis of the graph plots the trend in the light intensity distribution at the light intensity thought to form a 0.16-μm line width, against the x-axis which is the translucent region x of the mask converted to a value upon the wafer (x × reduction ratio of the projection optical system) that is further normalized in λ/NA.

[0040]

The simulation conditions were: exposure wavelength λ=248 nm, σ=0.3, and in the figure, black circles indicate NA=0.48, while white circles indicate NA=0.60. The trend in the light intensity distribution at the translucent region width upon a specific mask can be determined from the peak value. The typical trend in the light intensity distribution is for the exposure margin to become larger the greater the dimensions. This has the same meaning as even if dispersion in the margin is present within the pattern irradiation region, the trend is for the dimensional dispersion to become smaller the greater the light intensity distribution. Therefore, from this figure, in order to improve the

dimensional accuracy, the width x of the translucent region should preferably be within the range $0.5\ \lambda/NA \leq x \times$ (reduction ratio of the projection optical system) $\leq 0.8\ \lambda/NA$.

[0041]

In actual exposure, the width x of the translucent region of the phase-shift mask of the present invention is set to $0.65\ \lambda/NA$ after dimensional conversion to upon the wafer, and exposure was performed using a stepper with an exposure wavelength λ=248 nm, NA=0.48, σ=0.30. As a result of measuring the dimensions of the resist thus formed, we were able to obtain a pattern interval with a dimensional accuracy of 16 μm±10% with respect to a wide 0.16-μm line pattern.

[0042]

As described above, by setting a specific width for the translucent region of a phase-shift mask, high-precision pattern formation is possible independent of the pattern interval.

[0043]

Note that in embodiment 1, the phase-shift mask is a carved type, but it may also be a type consisting of stacked transparent films.

[0044]

[Meritorious Effects of the Invention]

As described above, by providing a mask construction by varying the width of translucent regions in phase-shift masks depending on the interval between line widths, or by using a pattern interval above a fixed value, or by always maintaining a fixed interval between translucent regions, the present invention is able to reduce dimensional dispersion due to the light proximity effect which occurs when using phase-shift masks.

[Brief Description of the Drawings]

[Fig. 1] This is a step cross section for the pattern formation method in Embodiment 1 of the present invention.

[Fig. 2] This is a structural diagram of the mask used in the pattern formation method in Embodiment 1 of the present invention.

[Fig. 3] This is a graph showing the light intensity distribution of the pattern formation method in Embodiment 1 of the present invention.

[Fig. 4] This is a graph showing the relationship between line width and the pattern interval in the pattern formation method in Embodiment 2 of the present invention.

[Fig. 5] This is a graph showing the relationship between line width and the pattern interval in the pattern formation method in Embodiment 3 of the present invention.

[Fig. 6] This is a structural diagram of the mask used in the pattern formation method in Embodiment 4 of the present invention.

[Fig. 7] This is a graph showing the relationship between the translucent region and the light intensity distribution in the pattern formation method in Embodiment 4 of the present invention.

[Fig. 8] This is a step cross section for the conventional pattern formation method.

[Explanation of Symbols]

1 ... Positive resist

2, 22 ... Substrate

3A, 3B, 23A, 23B ... Exposure light

4 ... Mask

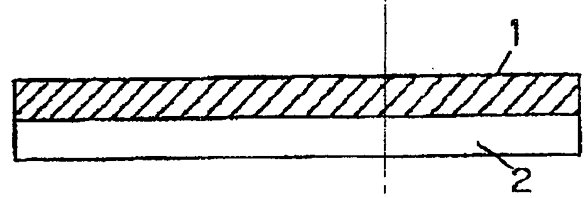
5, 5A, 5B, 15, 25 ... Opaque regions of mask

6A, 6B, 16A, 16B, 26A, 26B ... Translucent regions of mask

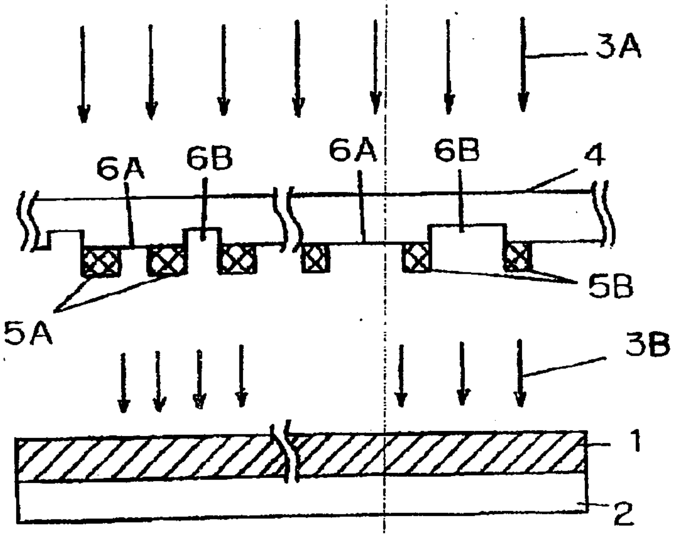
[Name of Document] Drawings

[Fig. 1]

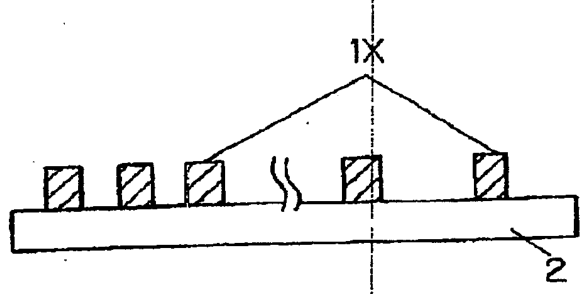
(a)



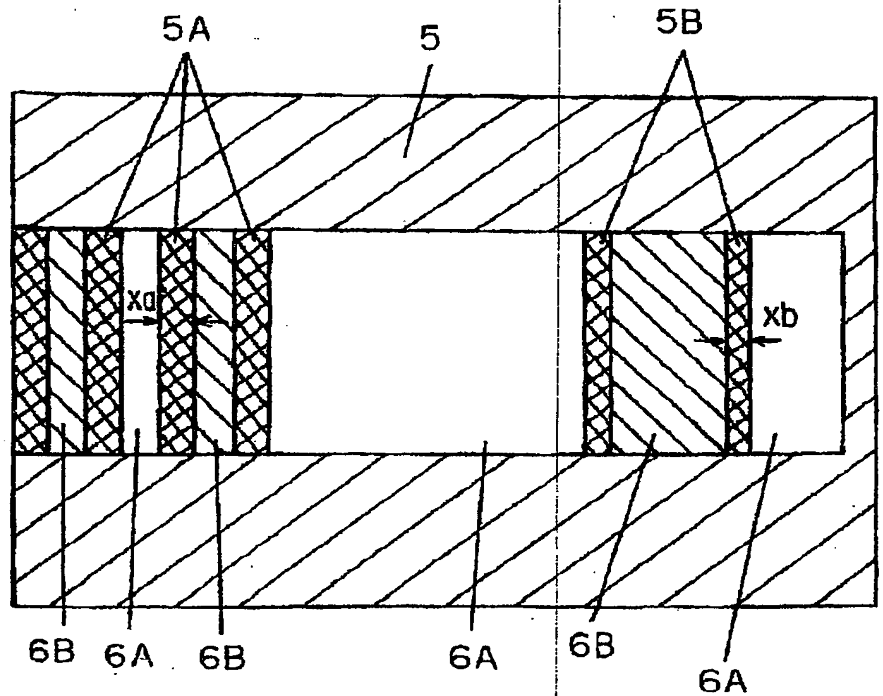
(b)



(c)

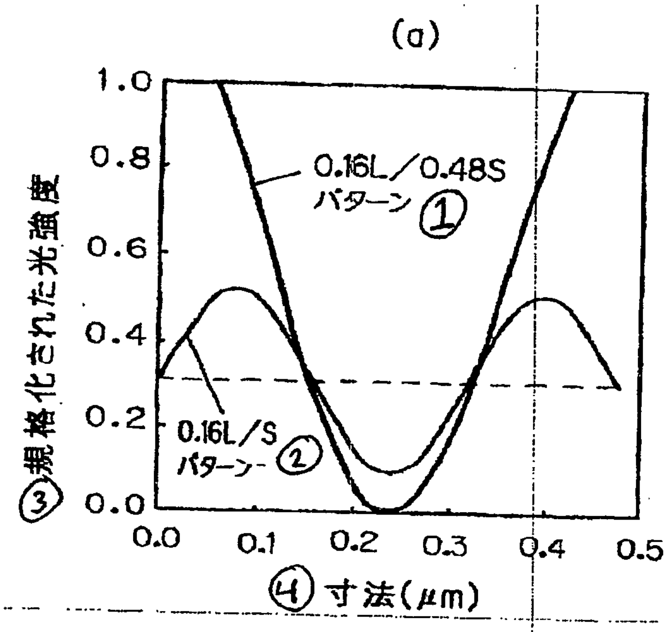


[Fig. 2]



[Fig. 3]

(a)

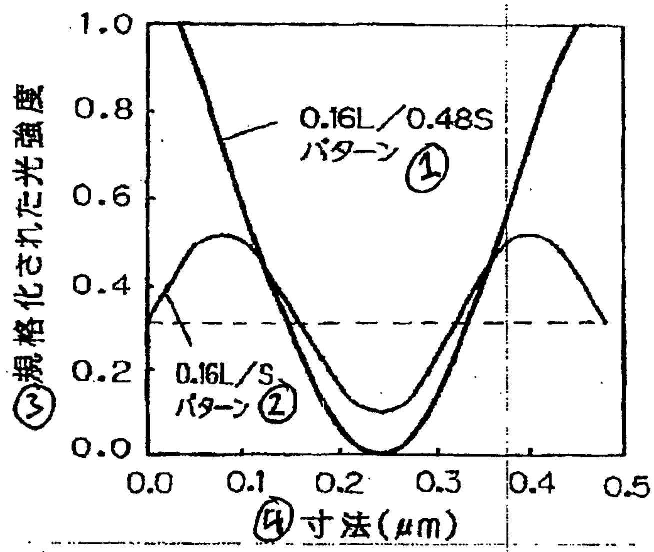


[Key]

1. 0.16L/0.48S pattern
2. 0.16L/S pattern
3. Normalized light intensity
4. Dimensions (μm)

(b)

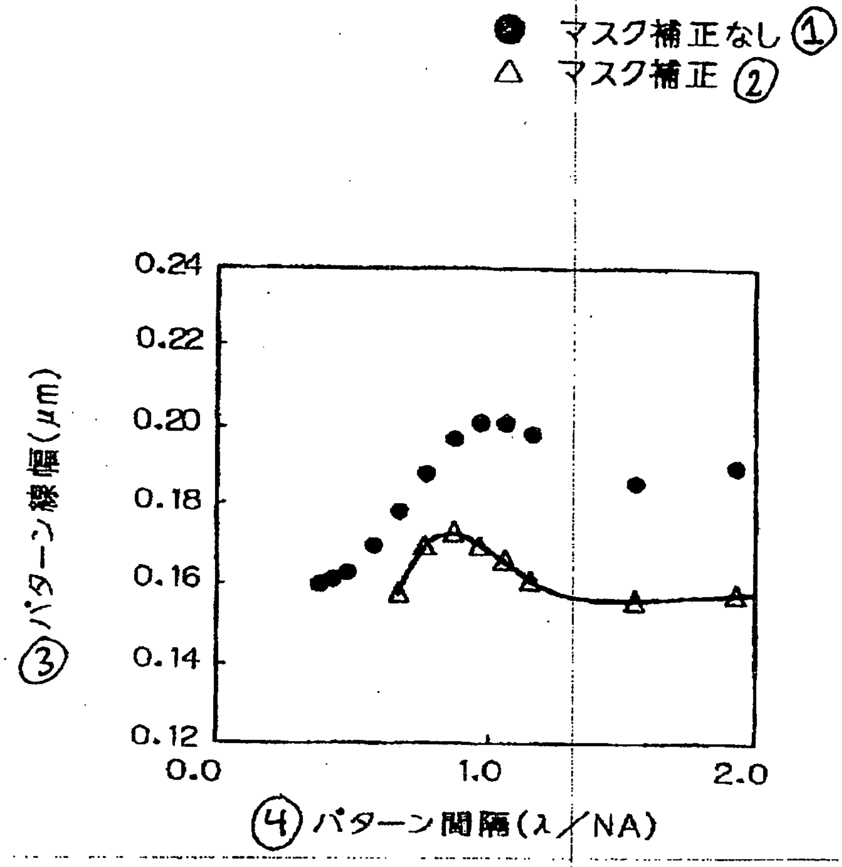
(b)



[Key]

1. 0.16L/0.48S pattern
2. 0.16L/S pattern
3. Normalized light intensity
4. Dimensions (μm)

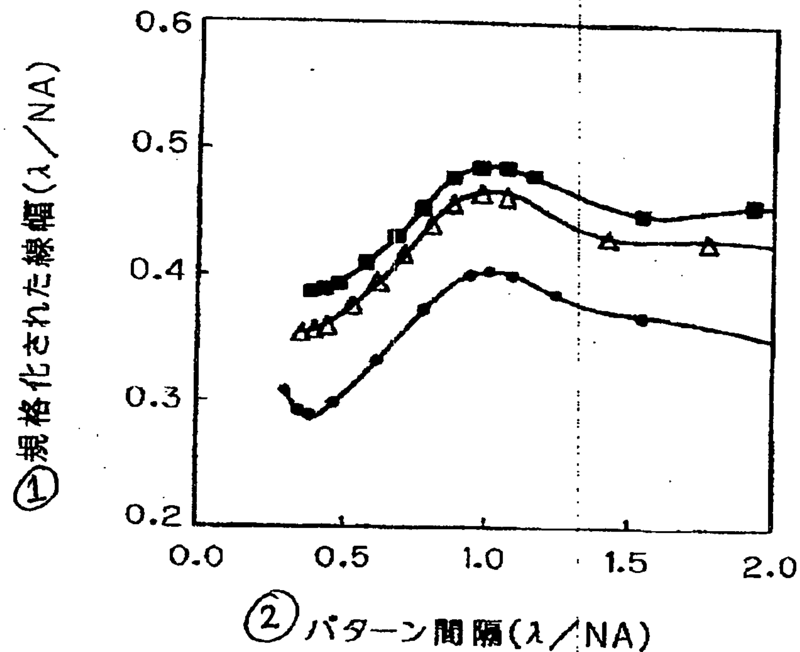
[Fig. 4]



[Key]

1. No mask compensation
2. Mask compensation
3. Pattern line width (μm)
4. Pattern interval (λ/NA)

[Fig. 5]

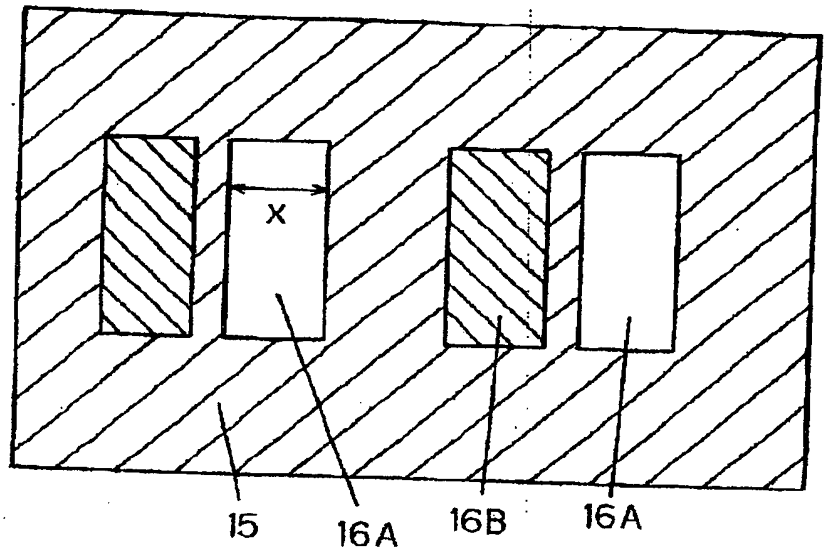


[Key]

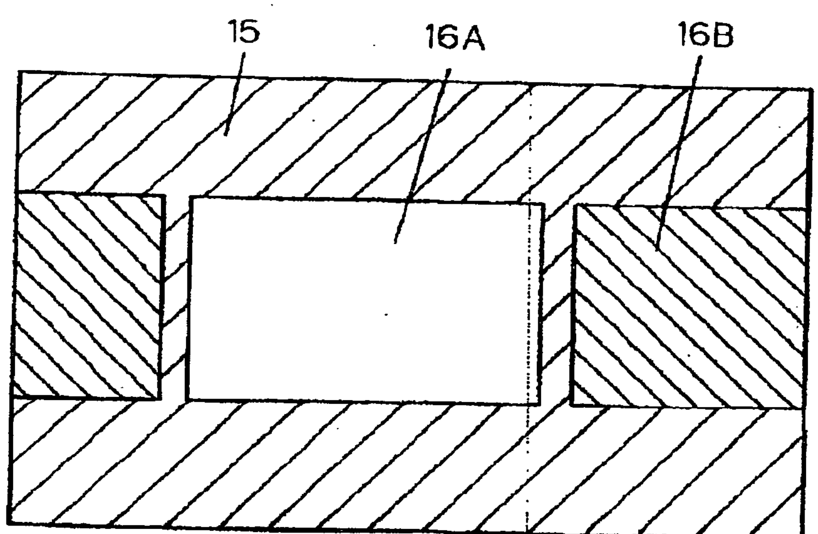
1. Normalized line width (λ/NA)
2. Pattern interval (λ/NA)

[Fig. 6]

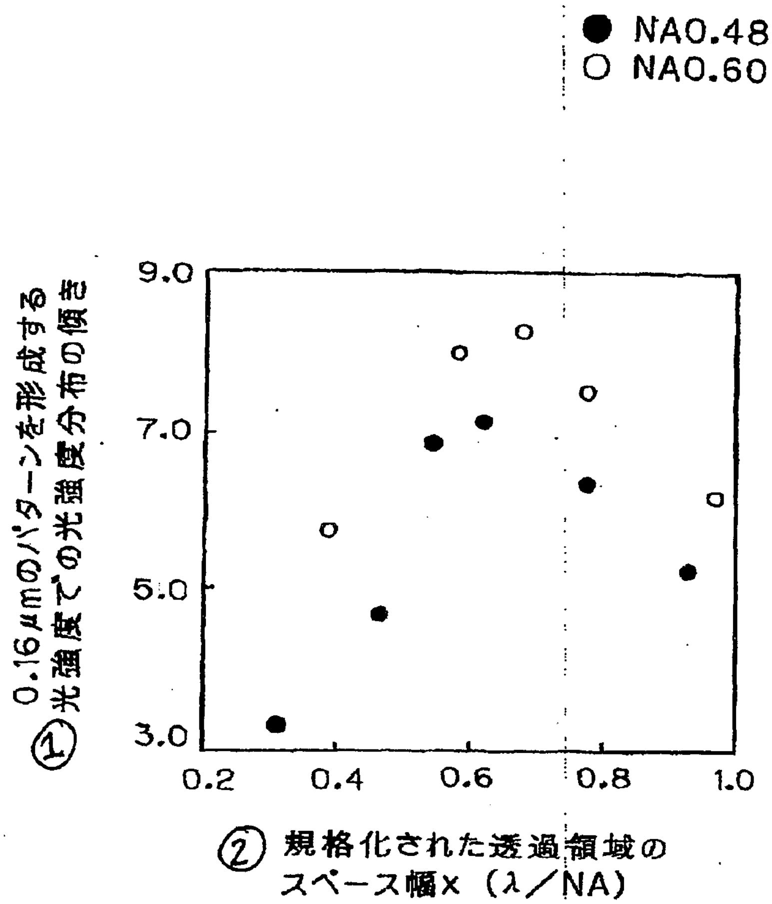
(a)



(b)



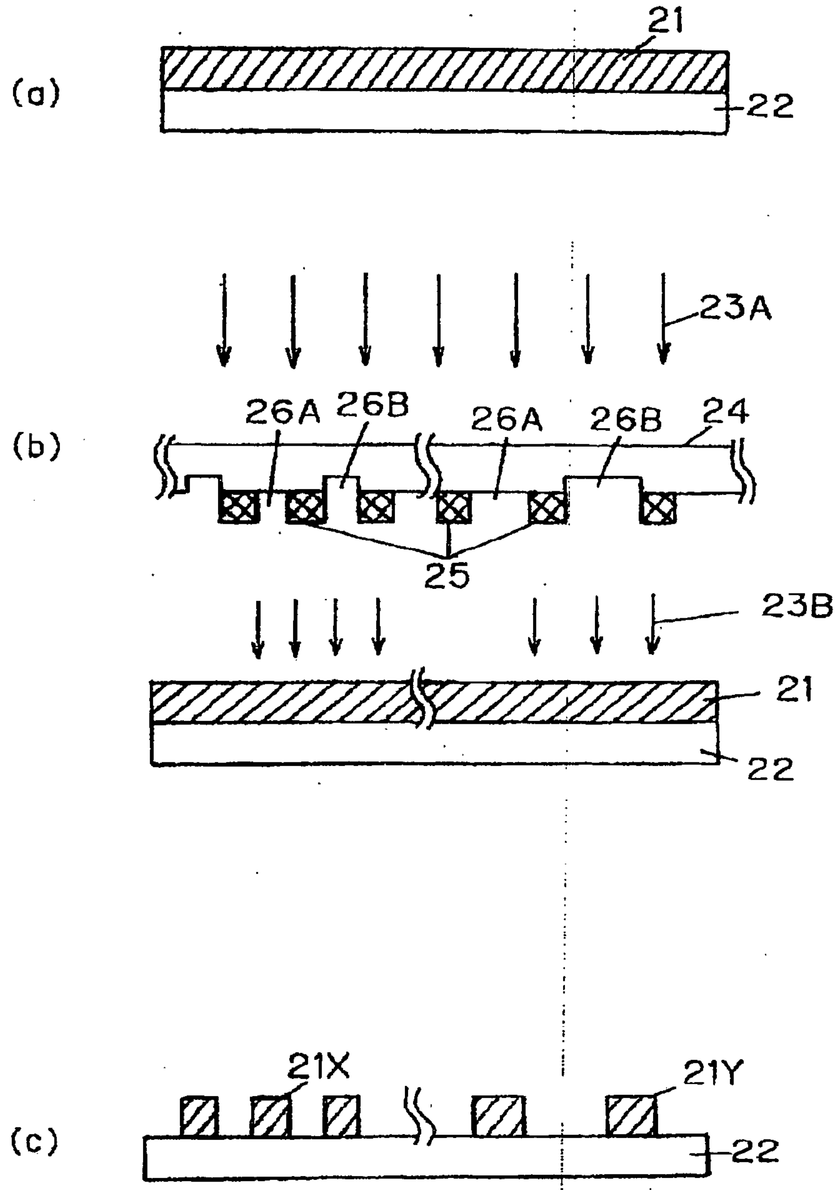
[Fig. 7]



[Key]

1. Trend in the light intensity distribution at the light intensity forming a 0.16-μm pattern
2. Normalized space width x in the translucent region (λ/NA)

[Fig. 8]



[Name of Document] Abstract

[Abstract]

[Problem]

In pattern formation using a phase-shift mask, the object is to suppress errors in dimensional accuracy based on differences in pattern intervals.

[Means of Solving]

At the time of using a phase-shift mask 4 with a phase difference of 180° in translucent regions with an opaque region interposed therebetween to form resist patterns, when exposing the positive resist 1, vary the widths of the opaque region 5A and the translucent region 5B of the mask 4 depending on the interval with the adjacent pattern, and thereby form a fine pattern of the same line width with good dimensional accuracy.

[Selected Figure] Fig. 1

Japanese Patent Application No. 8-236317

[Name of Document]	Official Amendment Data
[Amended Document]	Patent Application

<Authorization Information/Additional Information>

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